NPS-AM-11-C8P15R01-055

EXCERPT FROM THE

PROCEEDINGS

OF THE

EIGHTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM THURSDAY SESSIONS VOLUME II

The Effect of Processes and Incentives on Acquisition Cost Growth

Doug Bodner, Bill Rouse, and I-Hsiang Lee, Georgia Institute of Technology

Published: 30 April 2011

Prepared for the Naval Postgraduate School, Monterey, California 93943

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
APR 2011		**00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE	
The Effect of Processes and Incentives on Acquisition Cost Growth	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Georgia Institute of Technology,Tennenbaum Institute,Atlanta,GA,30332**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

Presented at the Naval Postgraduate School?s 8th Annual Acquisition Research Symposium, 10-12 May 2011, Seaside, CA. U.S. Government or Federal Rights License

14. ABSTRACT

Cost growth continues to be a serious concern in major acquisition programs. A variety of causes have been identified for cost growth, including low initial cost estimates, complex acquisition processes, and immature technologies. Incentivebased systems have been employed in an attempt at cost savings, with mixed results at best. This paper examines the role of process and incentive characteristics in cost growth. In particular, we study process concurrency, types of incentive contracts employed and the transfer point from cost-plus to fixed-price contracts, and the resulting effects on cost growth in the F-35 Joint Strike Fighter program. The F-35 program currently is in low-rate initial production. The emerging paradigm of organizational simulation is used in this study, since it combines process representations to model acquisition processes and agent representations to model multi-actor behavior, including reaction to incentives. Simulation experiments are conducted and analyzed to determine the effects of the factors described above on cost growth.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**42**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

To request Defense Acquisition Research or to become a research sponsor, please contact:

NPS Acquisition Research Program
Attn: James B. Greene, RADM, USN, (Ret.)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.acquisitionresearch.net

Preface & Acknowledgements

During his internship with the Graduate School of Business & Public Policy in June 2010, U.S. Air Force Academy Cadet Chase Lane surveyed the activities of the Naval Postgraduate School's Acquisition Research Program in its first seven years. The sheer volume of research products—almost 600 published papers (e.g., technical reports, journal articles, theses)—indicates the extent to which the depth and breadth of acquisition research has increased during these years. Over 300 authors contributed to these works, which means that the pool of those who have had significant intellectual engagement with acquisition issues has increased substantially. The broad range of research topics includes acquisition reform, defense industry, fielding, contracting, interoperability, organizational behavior, risk management, cost estimating, and many others. Approaches range from conceptual and exploratory studies to develop propositions about various aspects of acquisition, to applied and statistical analyses to test specific hypotheses. Methodologies include case studies, modeling, surveys, and experiments. On the whole, such findings make us both grateful for the ARP's progress to date, and hopeful that this progress in research will lead to substantive improvements in the DoD's acquisition outcomes.

As pragmatists, we of course recognize that such change can only occur to the extent that the potential knowledge wrapped up in these products is put to use and tested to determine its value. We take seriously the pernicious effects of the so-called "theory–practice" gap, which would separate the acquisition scholar from the acquisition practitioner, and relegate the scholar's work to mere academic "shelfware." Some design features of our program that we believe help avoid these effects include the following: connecting researchers with practitioners on specific projects; requiring researchers to brief sponsors on project findings as a condition of funding award; "pushing" potentially high-impact research reports (e.g., via overnight shipping) to selected practitioners and policy-makers; and most notably, sponsoring this symposium, which we craft intentionally as an opportunity for fruitful, lasting connections between scholars and practitioners.

A former Defense Acquisition Executive, responding to a comment that academic research was not generally useful in acquisition practice, opined, "That's not their [the academics'] problem—it's ours [the practitioners']. They can only perform research; it's up to us to use it." While we certainly agree with this sentiment, we also recognize that any research, however theoretical, must point to some termination in action; academics have a responsibility to make their work intelligible to practitioners. Thus we continue to seek projects that both comport with solid standards of scholarship, and address relevant acquisition issues. These years of experience have shown us the difficulty in attempting to balance these two objectives, but we are convinced that the attempt is absolutely essential if any real improvement is to be realized.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the Acquisition Research Program:

- Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
- Program Executive Officer SHIPS
- Commander, Naval Sea Systems Command
- Army Contracting Command, U.S. Army Materiel Command
- Program Manager, Airborne, Maritime and Fixed Station Joint Tactical Radio System

- Program Executive Officer Integrated Warfare Systems
- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
- Deputy Assistant Secretary of the Navy (Acquisition & Logistics Management)
- Director, Strategic Systems Programs Office
- Deputy Director, Acquisition Career Management, US Army
- Defense Business Systems Acquisition Executive, Business Transformation Agency
- Office of Procurement and Assistance Management Headquarters, Department of Energy

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this Symposium.

James B. Greene, Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

Panel 15 – Analysis for Enhanced Acquisition Decision-Making

Thursday, May 12, 2011	
9:30 a.m. – 11:00 a.m.	**Chair: J. David Patterson,** Executive Director, National Defense Business Institute, The University of Tennessee ***The Effect of Processes and Incentives on Acquisition Cost Growth*** Doug Bodner, Bill Rouse, and I-Hsiang Lee, Georgia Institute of Technology ***The Failures and Promises of an Operational Service-Oriented Architecture: The ROI of Operational Effectiveness in Addition to Acquisition Efficiency at the Navy's Op Level of War*** Richard Suttie, U.S. Naval War College, and Nicholas Potter ***The Theory and Feasibility of Implementing an Economic Input/Output Analysis of the Department of Defense to Support Acquisition Decision Analysis and Cost Estimation*** Eva Regnier and Dan Nussbaum, NPS

David Patterson—Executive Director, National Defense Business Institute, University of Tennessee. Mr. Patterson is establishing an institution inspiring business innovation for both government and industry at the University of Tennessee in the College of Business Administration by providing practical, sound assistance in creating economically efficient and effective Defense business and acquisition programs. He is responsible for preparing funding proposals and budgets and for recruiting and managing university staff, professors, other faculty members, and key subject-matter experts engaged in relevant research and resource development tasks.

Prior to his current duties, he was the Principal Deputy Under Secretary of Defense (Comptroller). As the Principal Deputy, he was directly responsible for advising and assisting the Under Secretary of Defense (Comptroller) with development, execution, and oversight of the DoD budget, exceeding $515 billion, with annual supplemental requests of more than $160 billion. He was also responsible for developing legislative strategies and developing and implementing DoD financial policy, financial management systems, and business modernization programs. In June 2005 Mr. Patterson was appointed to lead the Defense Acquisition Performance Assessment Project, a comprehensive evaluation of every aspect of the Defense Department acquisition system and decision making processes.

From August 2003 to June 2005, Mr. Patterson held duties as The Special Assistant to the Deputy Secretary of Defense. In the capacity as Special Assistant, Mr. Patterson was responsible for managing the Deputy Secretary of Defense's personal staff as well as providing direction and advice to the Office of the Secretary of Defense Staff on a wide range of national security operations and policy subjects. He contributed to the Department of Defense support to the United States' mission to establish free and economically successful societies and governments in Iraq and Afghanistan. Additionally, Mr. Patterson supported the Deputy Secretary in the areas of military commissions for detainees in the Global War on Terrorism and major defense acquisition programs.

Before returning to government service, Mr. Patterson was a founding and managing partner at Bucher, Hutchins, Kohler and Patterson, Inc., where he led the firm's commercial consulting practice, developing management strategies for acquiring new business. From 1999 to 2001, he was the Vice

President and Site Manager for Steven Myers and Associates' support to Lockheed Martin Corporation's winning Joint Strike Fighter competitive proposal preparation.

Between 1993 and 1999, Mr. Patterson held a variety of responsible, executive positions at McDonnell Douglas Corporation (later The Boeing Company), beginning as the Senior Manager for Market Research and Analysis on the C-17 military air cargo aircraft and later as Director, International Business Development. He was responsible for developing and executing the business capture strategy that won U.S. Government Defense Acquisition Board approval to procure 80 additional C-17s, completing the first contract for 120 aircraft. Mr. Patterson led the Boeing business development team that launched the initiative to introduce a commercial version of the C-17; the BC-17.

Mr. Patterson served in the Air Force from 1970 to 1993, retiring in the rank of colonel. During that time, he held responsible leadership and management positions, with assignments at the air wing level as a C-5A aircraft commander and Deputy Operations Group Commander, at major command headquarters, Headquarters, U.S. Air Force, the Office of the Chairman, Joint Chiefs of Staff and the Office of the Secretary of Defense, Inspector General. In 1986, Mr. Patterson was the Air Force Fellow at the American Enterprise Institute. He served in Vietnam flying O2As as forward air controller.

The Effect of Processes and Incentives on Acquisition Cost Growth

Doug Bodner—Senior Research Engineer, Tennenbaum Institute, Georgia Institute of Technology. Dr. Bodner's research focuses on computational analysis and decision support for design, operation, and transformation of organizational systems. His work has spanned a number of industries, including automotive, electronics, energy, health care, military acquisition, paper and pulp, semiconductors, and telecommunications. He is a senior member of the Institute of Electrical and Electronics Engineers (IEEE) and the Institute of Industrial Engineers (IIE), and a member of the Institute for Operations Research and Management Science (INFORMS). He is a registered professional engineer in the state of Georgia. [doug.bodner@gatech.edu]

Bill Rouse—Executive Director, Tennenbaum Institute, Georgia Institute of Technology. Dr. Rouse is also a professor in the College of Computing and School of Industrial and Systems Engineering. He has written hundreds of articles and book chapters and has authored many books, including most recently *People and Organizations: Explorations of Human-Centered Design* (Wiley, 2007), *Essential Challenges of Strategic Management* (Wiley, 2001), and the award-winning *Don't Jump to Solutions* (Jossey-Bass, 1998). He is editor of *Enterprise Transformation: Understanding and Enabling Fundamental Change* (Wiley, 2006), co-editor of *Organizational Simulation: From Modeling & Simulation to Games & Entertainment* (Wiley, 2005), co-editor of the best-selling *Handbook of Systems Engineering and Management* (Wiley, 1999), and editor of the eight-volume series *Human/Technology Interaction in Complex Systems* (Elsevier). Among many advisory roles, he has served as Chair of the Committee on Human Factors of the National Research Council, a member of the U.S. Air Force Scientific Advisory Board, and a member of the DoD Senior Advisory Group on Modeling and Simulation. Rouse is a member of the National Academy of Engineering, as well as a fellow of four professional societies—Institute of Electrical and Electronics Engineers (IEEE), the International Council on Systems Engineering (INCOSE), the Institute for Operations Research and Management Science, and the Human Factors and Ergonomics Society. [bill.rouse@ti.gatech.edu]

I-Hsiang Lee—Graduate Research Assistant, Tennenbaum Institute. Mr. Lee is a PhD student in the School of Industrial & Systems Engineering at the Georgia Institute of Technology and is working on research of organizational simulation. He received a BSE in Computer Science and Information Engineering from National Taiwan University, Taiwan. He also holds an MS in Computer Science and an MEng in Operation Research and Information Engineering from the University of California at Santa Barbara and Cornell University, respectively. [ethan@gatech.edu]

Abstract

Cost growth continues to be a serious concern in major acquisition programs. A variety of causes have been identified for cost growth, including low initial cost estimates, complex acquisition processes, and immature technologies. Incentive-based systems have been employed in an attempt at cost savings, with mixed results at best. This paper examines the role of process and incentive characteristics in cost growth. In particular, we study process concurrency, types of incentive contracts employed and the transfer point from cost-plus to fixed-price contracts, and the resulting effects on cost growth in the F-35 Joint Strike Fighter program. The F-35 program currently is in low-rate initial production. The emerging paradigm of organizational simulation is used in this study, since it combines process representations to model acquisition processes and agent representations to model multi-actor behavior, including reaction to incentives. Simulation experiments are conducted and analyzed to determine the effects of the factors described above on cost growth.

Introduction

Cost growth has been a significant problem in major DoD acquisition programs. A recent report from the Government Accountability Office (GAO) notes that, for the fiscal year 2008 portfolio of weapons systems, there has been cost growth of $296 billion (GAO, 2009). In addition, since 2008, GAO (2011) notes that there has been $135 billion in total cost growth, $70 billion of which cannot be explained by changes in quantities ordered. Cost growth can result in fewer systems being produced than envisioned or desired (e.g., F-22), or in program cancellation (e.g., Navy Area Missile Defense). In the current and projected fiscal environment, there is considerable pressure to rein in cost growth.

Cost growth is a complex phenomenon involving technical issues, decision-making, contractor performance, and uncertainty. Therefore, it is not easily addressed or sometimes even properly understood. One way to study systems exhibiting uncertainty is computer simulation, in which a model of the system to be studied is specified and then analyzed to determine the system's performance with respect to different criteria under different conditions. In computer simulation, experiments can be conducted without using the real system, which is advantageous for many types of systems that simply would not be used for experimentation. Here, we are interested in studying acquisition processes, which encompass technical issues and technical decision-making, and incentives, which affect contractor performance and decision-making.

The remainder of this paper is organized as follows. The Acquisition Processes, Incentives, and Cost Growth section discusses the issues involved in cost growth from a process and incentive perspective. The Model Description section introduces and describes a model of the acquisition enterprise using organizational simulation, a relatively new paradigm for simulating enterprise systems. The Experimental Example section presents some simulation results illustrating the model concepts. The final section concludes with a discussion on future research.

Acquisition Processes, Incentives, and Cost Growth

Cost growth occurs for a variety of reasons, including uncertainty and lack of knowledge about technology, design, and manufacturing (GAO, 2009a). Candreva (2009) points to the role of institutional factors in organizational failures such as cost growth. Our previous research has addressed cost by focusing on the process aspects of acquisition. For instance, we have demonstrated that evolutionary acquisition processes can yield quicker deployment of capability than traditional acquisition processes, but at potentially higher cost due to overhead from the increased frequency of development cycles (Pennock & Rouse, 2008). System modularity tends to reduce the overall life cycle cost when sustainment is considered and can mitigate higher costs associated with larger production levels, thus reducing the effect of cost growth (Bodner, Rahman, & Rouse, 2010). However, such process modeling does not capture the effect of incentives, which can be an effective approach to achieving contractor performance, if properly applied (Tremaine, 2008).

Incentives and contract structures potentially play an important role in cost control. The two main types of contract structures are cost-plus, in which the government reimburses the contractor for costs incurred and pays an additional amount for profit, and fixed-price, in which the government pays a fixed price for a set deliverable (e.g., number of systems). Typically, the particular type of contract structure is used based on the risk profile of the program. Programs associated with high levels of research and development tend to use cost-plus contracts, since research and development entail significant risk for the contractor. Cost-plus contracts shift that risk to the government. Fixed-price contracts, on the other hand, are used for production, in which costs are more certain. Fixed-price contracts shift risk to the contractor.

Incentives traditionally have been implemented via such contract mechanisms as cost-plus-incentive-fee (CPIF) or cost-plus-award-fee (CPAF). An incentive fee rewards cost control, while an award fee rewards performance related to non-cost outcomes. Outcomes may relate to system capabilities (e.g., speed, altitude) or targets over time, such as the emerging concept of performance-based logistics (Kratz & Buckingham, 2009). Award fees may be structured to occur within certain evaluation periods, and a rollover may be used to transfer an unearned fee to a future period in which it can be earned. Competition, as opposed to non-competition, can also be considered as an incentive for a contractor (Birkler et al., 2001), although use of competition is constrained in areas such as aircraft acquisition, due to industry consolidation (Birkler et al., 2003). An award fee structure for spiral development of software-intensive systems is presented by Reifer and Boehm (2006).

The fundamental idea is to tie the incentive to the desired outcomes. This has not always worked in practice, however. A recent GAO report finds that the current DoD practice of using award and incentive fees is ineffective (GAO, 2005). Award fees often are provided despite the contractor's not having met performance criteria, and incentive fees have not been shown to motivate contractors to control costs. In addition, DoD does not have a system to allow sharing of case studies demonstrating successful use of award or incentive fees.

Recent studies have addressed increasing the effectiveness of award fees and incentive fees. Using an analytic approach, Hildebrandt (2009) develops guidelines for effective decision-making and information availability structures applied to incentive contracts. Under some arrangements, the information required may be demanding. Four programs are examined by Gilbreth and Hubbard (2008) to develop recommendations for effective incentive use. These recommendations include adequate training and feedback, plus several specific recommendations for award fees (using a base fee, setting the award fee based on outcomes rather than time, relating the award fee to the outcomes achieved, and using rollovers judiciously). These results are confirmed and extended by a continuation of the study that examined 25 programs (Tremaine, 2008).

Consider the F-35 program, which is developing and producing three variants of a next-generation tactical fighter for three Service applications (Air Force, Navy, and Marines). This program currently is in low-rate initial production (LRIP). The program has seen significant cost growth and schedule slippage (GAO, 2009b). There are a variety of causes cited, including immature technologies in development, ongoing design changes, inefficient production processes, and incomplete testing (GAO, 2011). Concerns due to the cost of the program have caused the National Commission on Fiscal Responsibility and Reform to recommend significant reductions in quantities to be procured (NCFRR, 2010) and have also prompted discussions of cancelling the Marine variant (short takeoff and landing). Nevertheless, the program has recently entered into its fourth phase of LRIP with a switch from a cost-plus contract to a fixed-price contract.

In addition, the F-35 program is of interest due to the highly distributed nature of the design and production network of contractors. In previous aircraft programs (e.g., F-16), the aircraft was largely designed and built by the prime contractor, with sourcing of somewhat simple components from suppliers. With the F-35, major subsystems are sourced for design and production to other contractors, many of which are international (Kapstein, 2004). Hence, the problem of government’s incentivizing the contractor really becomes more complex, as the prime contractor, in the role of lead systems integrator (LSI), must in turn incentivize partners and other contractors.

The intent here is not specifically to study the F-35 program but rather to study the interaction of process and incentive issues raised by the program in the context of cost growth.

Model Description

This research uses the emerging paradigm of organizational simulation (Rouse & Boff, 2005) to study the problem of acquisition cost growth. Traditional simulations used to study organizations can be divided into three major paradigms: discrete-event (Law & Kelton, 2000), system dynamics (Sterman, 2000), and agent-based (Hillebrand & Stender, 1994). Discrete-event simulation tends to emphasize the transactional nature of process-based systems. System dynamics, on the other hand, represents continual accumulation processes affected by feedback flows and lags. Both are suitable for studying process-based systems, depending on the particular level of model resolution and focus. Agent-based simulation is relatively new and emphasizes the interaction of actors in a system. Thus, it has seen significant use in social science research applications. Of interest here is its application to economic behavior.

Organizational simulation uses elements of these three paradigms to model process and actor behaviors in organizational systems. It has been used in several domains thus far, including research and development investment (Bodner & Rouse, 2007), health care delivery (Rouse & Bodner, 2009), and computer server design and development (Bodner, Mutnury, Cases, & Rouse, 2009).

Process Model

Per DoD acquisition policy, acquisition is divided into a number of phases whereby a program evolves from concept to deployed systems. These phases consist of concept refinement, technology development, system development and demonstration, production and deployment, and operations and support. Various milestones and reviews exist in the process and serve as gates through which the program must have made sufficient technical progress to pass. As the program progresses, costs are incurred and are monitored against estimated costs. In addition, at various points in the process, contracts are awarded that cover specific deliverables relative to an acquisition phase. At these points, the amount of the contract, the deliverables, and the structure of the contract are in play. The process model is shown in Figure 1.

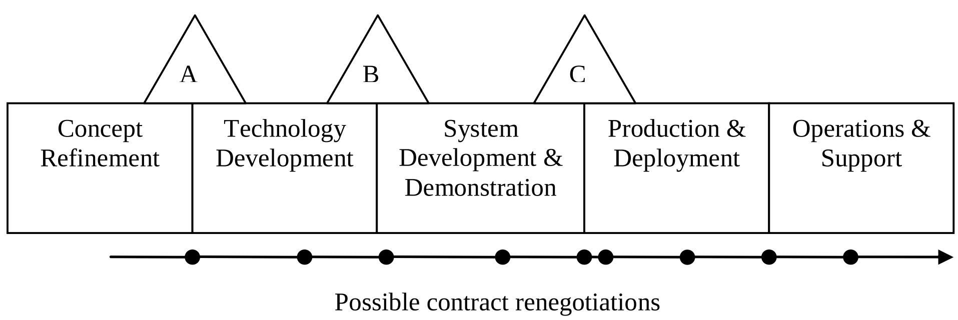


Figure 1. Acquisition Processes

Note that sometimes concurrency occurs, especially between system testing (in system development & demonstration) and low-rate initial production (in production and deployment). While this can expedite system delivery, it also entails risks, since manufacturing an unproven system may entail redesign and rework if undiscovered flaws exist. This risk relates directly to potential cost growth.

Actor Model

The actor model consists of the set of actors, their behaviors, and their interactions with one another. The government is one actor, and then contractors are modeled as separate actors.

Given that we are interested in incentives, we use the principal-agent framework as the basis for modeling actor interactions. The principal-agent framework is used in micro-economics to model the interaction of two actors, one of which (the principal) utilizes another (the agent) to perform a task (Kreps, 1990). This framework introduces a number of problems such as moral hazard and information asymmetry. Typically, the principal must design a contract mechanism that works to motivate the agent and hopefully addresses any problem situations.

In the case of acquisition, the government serves as the principal and the prime contractor as its agent. In turn, other contractors may be agents to the prime contractor's role as principal. In a complex supply network, the principal-agent representation can be used to model the many different tiers of contractors that exist, as shown in Figure 2. Note that a contractor can be an agent to multiple other contractors. Sometimes this is known to the principals; other times, it is not known. In addition, a contractor may be an agent to multiple contractors located in different programs (i.e., different supply networks under different prime contractors, who may be competitors). Thus, the principal-agent relations in a real supply network can be quite complex. Such complexity is usually not solvable by analytic models, leaving simulation as an important method in their study.

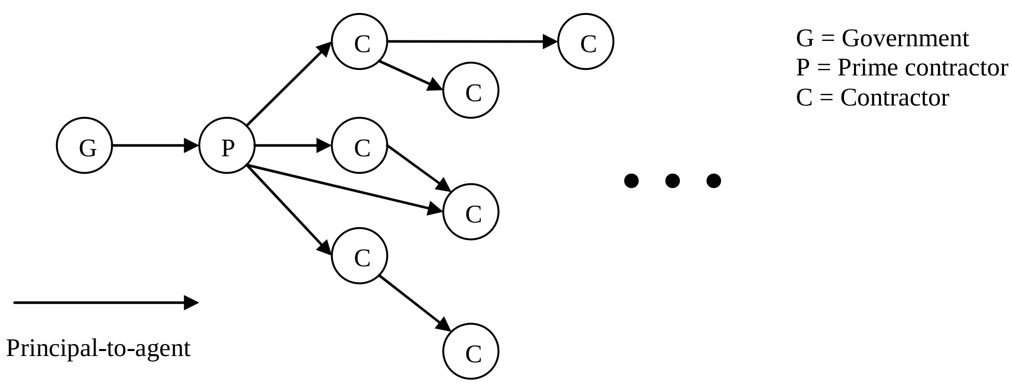


Figure 2. Actor Network

Incentive Model

Here, we describe a simplified incentive model that can serve as the basis for a principal-agent model of acquisition. Assume that the government is the principal and that the prime contractor is its agent. The agent has a utility function representing value received from working for the principal. We assume a functional form as shown in Equation 1, where *U* represents the utility, *w* represents the contractual payment from principal to agent (with diminishing marginal returns), and *a* represents the effort expended by the agent. In the case where there is no contract, the agent maintains a reservation utility U_r.

$$U(w, a) = \sqrt{w} - a \tag{1}$$

To simplify, we assume that the agent can expend a high level of effort a_h or a low level of effort a_l during the contractual term. Obviously, $a_h > a_l$. Now suppose that the principal and agent enter into a performance-based contract whereby the agent is paid according to its performance during the period. Again, for the sake of simplicity, we assume three levels of performance (low, medium, and high). Payment is as follows.

- The agent is paid x02 if performance is low.
- The agent is paid x12 if performance is medium.
- The agent is paid x22 if performance is high.

Obviously, $x_0 < x_1 < x_2$. The performance is uncertain, but it is based in part on the level of effort expended by the agent. Let *P*(*a*) be the performance level achieved by the agent as a function of effort, and assume that there are three levels of performance—P_0 (low), P_1 (medium), and P_2 (high) —with $P_0 < P_1 < P_2$. We model the performance according to the following functional form.

$$P(a_l) = \begin{cases} P_0 & \text{with probability } p_0^l \\ P_1 & \text{with probability } p_1^l, \text{ where } \sum_{i=0}^{2} p_i^l = 1 \\ P_2 & \text{with probability } p_2^l \end{cases} \tag{2}$$

$$P(a_h) = \begin{cases} P_0 & \text{with probability } p_0^h \\ P_1 & \text{with probability } p_1^h, \text{ where } \sum_{i=0}^{2} p_i^h = 1 \\ P_2 & \text{with probability } p_2^h \end{cases} \tag{3}$$

The terms p_i^l and p_i^h represent, respectively, probabilities associated with mapping the agent's effort (low or high) to performance outcomes. Even if the agent expends high effort, there is a probability of low or medium performance. We assume, however, that low effort is more highly correlated with low performance than with high performance and vice versa. Thus, we assume that $p_0^l > p_1^l > p_2^l$ and $p_0^h < p_1^h < p_2^h$.

With regard to the contractual agreement, there are three scenarios. The agent can decline the contract, the agent can accept the contract and expend low effort, or the agent can accept the contract and expend high effort. In the former case, the agent's utility is simply the reservation utility U_r. In the latter two cases, the agent's expected utility is given in Equation 4.

$$E\left[U(a_j)\right] = \sum_{i=0}^{2} p_i^j x_i - a_j, \text{ for } j = l, h \tag{4}$$

The contract can be viewed from the perspective of either the principal or the agent. The principal, of course, wants the agent to expend maximum effort so as to maximize the chance of high performance. On the other hand, the principal does not want to overpay the agent. Thus, one way in which the principal's objective can be stated is to minimize the payment subject to the condition that the agent expends high effort.

$$\text{Minimize} \quad \sum_{i=0}^{2} p_i^h x_i^2 \tag{5}$$

From the agent's perspective, the only value from expending high effort occurs when the expected utility from high effort is greater than both the reservation utility and the expected utility of expending low effort. That is,

$$E[U(a_H)] \geq U_r \qquad (6)$$

$$E[U(a_H)] \geq E[U(a_L)] \qquad (7)$$

Combining Equations 5–7 yields a constrained optimization problem, which is solvable if the values for parameters are known and fixed.

Cost-Plus Model

As the agent works on behalf of the principal, it incurs costs for effort. We assume, in general, that the cost incurred a_t over time horizon t during a particular acquisition phase has a fixed set-up cost a_0 and then is linear in time with respect to a constant burn rate m, where m is dependent on the level of effort and where t is measured from the beginning of the phase.

$$a_t = a_0 + mt \qquad (8)$$

From a cost-plus perspective, for the agent to be interested in the contract, payment from the principal must cover the agent's cost and then provide a profit. Moreover, the utility from the principal's payment and the agent's cost (Equation 1) must be greater than the agent's reservation utility.

In cost-plus arrangements, the duration of the acquisition phase can be estimated but often varies from the estimate, driving cost growth. Ideally, the principal desires that the agent expend high effort, expecting performance to be high. From this, the principal can estimate the time remaining in an acquisition phase, as well as a cost.

Let T be the total completion time needed for an acquisition phase. Let $\hat{T}_0^r$ be the initial estimate for time remaining (i.e., $\hat{T}_0^r$ is an estimate for T), and let $\hat{T}_t^r$ be the remaining left for completion at time t (i.e., once the phase has commenced). At the end of each year t, the time remaining can be updated as follows, where the agent's performance is measured in time progression toward completion.

$$\hat{T}_{t+1}^r = \hat{T}_t^r - P(a_t) \qquad (9)$$

Note that the phase would end when $\hat{T}_t^r$ reaches zero for some t, at which time T becomes known. Assuming that the principal pays the agent annually for the contract duration, the principal's cost c_t in year t can be computed.

$$c_t = \begin{cases} x_t^L & \text{if the agent's performance is low} \\ x_t^M & \text{if the agent's performance is medium} \\ x_t^H & \text{if the agent's performance is high} \end{cases} \qquad (10)$$

Let C_T be the total cost to the principal for the acquisition phase, and let $\hat{C}_T^t$ be the estimate for C_T at time t. Letting C_t be the cost incurred by the end of year t, total costs can be tracked and the estimated phase cost can be updated.

$$C_t = C_{t-1} + c_t \qquad (11)$$

$$\hat{C}_T^t = C_t / (1 - (\hat{T}_t^r / (t + \hat{T}_t^r))) \qquad (12)$$

Letting C_t^0 be the initial estimate of costs to be incurred by year *t* (t = 1, 2,… T_s) allows incremental cost growth to be measured as $C_t - C_t^0$ and total cost growth to be estimated as $C_{T_s} - C_{T_s}^0$.

Fixed-Price Model

Suppose that the principal uses a fixed-price contract for the agent's work. We assume a firm fixed-price contract, rather than an instrument that allows some cost to be transferred from the agent to the principal. Hence, cost growth is not an issue for the principal. This situation typically occurs in production, where there is less outcome risk. Here, economies of scale are usually present. In micro-economics, economies of scale are modeled using a Cobb-Douglas production function (Kreps, 1990). Let *X* be the amount of input resources, in terms of labor, capital, and materials; *N* be the output in terms of number of units produced; and *b* be the scale factor. The fundamental relation between input and output is shown in Equation 13.

$$N = X^b \qquad (13)$$

If *b* > 0, then there are increasing returns to scale, meaning that the production is more efficient as more units are produced. This discussion assumes application in production, although the model may be extended to other phases. Assuming a constant per-unit cost of input *B*, the total cost of the production phase can be modeled as follows:

$$C_T = BX = BN^{1/b} \qquad (14)$$

The term $\alpha = 1/b$ is defined as the production efficiency. The production efficiency is the performance measure used for the agent, and the unit cost of input is the level of effort. Similar to the cost model, we use three different levels—α_0 (low), α_1 (medium), and α_2 (high)—with $\alpha_0 < \alpha_1 < \alpha_2$ (lower α implies better efficiency). Similar to the cost model, the effort has two levels: B_l (low effort) and B_h (high effort). A higher effort may involve, for example, more investment per unit of labor in training or per production line in precision machinery, with the intent to achieve better downstream efficiency. Thus, $B_h > B_l$. Note that there may be a fixed cost associated with effort that is not modeled here. Equations 15 and 16 relate performance to effort in a probabilistic framework as before, with $\varphi_0^l > \varphi_1^l > \varphi_2^l$ and $\varphi_0^h < \varphi_1^h < \varphi_2^h$.

$$\alpha(B_l) = \begin{cases} \alpha_0 & \text{with probability } \varphi_0^l \\ \alpha_1 & \text{with probability } \varphi_1^l \\ \alpha_2 & \text{with probability } \varphi_2^l \end{cases}, \text{where } \sum_{i=0}^{2} \varphi_i^l = 1 \qquad (15)$$

$$\alpha(B_h) = \begin{cases} \alpha_0 & \text{with probability } \varphi_0^h \\ \alpha_1 & \text{with probability } \varphi_1^h \\ \alpha_2 & \text{with probability } \varphi_2^h \end{cases}, \text{where } \sum_{i=0}^{2} \varphi_i^h = 1 \qquad (16)$$

If the agent chooses to enter into a fixed-price contract with the principal, where *Y* is the per-unit output price, the agent then must choose what level of effort to expend based on the expected gain *G*(*B*), which is a function of payment from the principal and costs associated with production and with effort.

$$E\left[G(B_j)\right] = NY - \sum_{i=0}^{2} \varphi_i^j B_j N^{\alpha_i}, \ for\ j = l, h \qquad (17)$$

The agent selects the level of effort whereby $E[U(P_\alpha)]$ is maximized. However, this formulation does not address two of the principal's concerns regarding the contract—the selection of an appropriate value of *Y* and the timely delivery of output units. The performance measure α is primarily of interest to the agent unless it can be translated into schedule performance. Two methods of doing this are using a discounted cash flow model for the payments and costs and applying penalties to the payments when the schedule is not met. These methods are the subject of current work.

Simulation Implementation

A simulation model using the preceding constructs has been implemented using an organizational simulation framework. This framework uses AnyLogic, a commercially available simulation software product, plus a set of customized classes to model organizational artifacts and behaviors (Bodner, 2009). This allows actors to be modeled using an agent-based approach and acquisition processes to be modeled using a discrete-event, process/transactional approach. The interaction of these two approaches is shown in Figure 3. Note that not all possible behavioral interactions or structural relationships are shown.

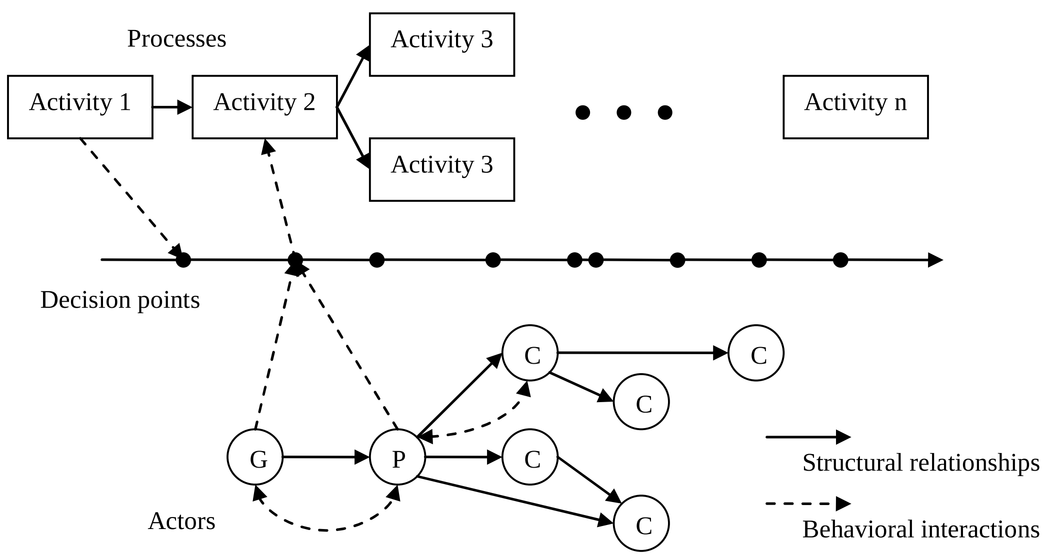


Figure 3. Process-Actor Interaction

This paper focuses on the implementation of a principal-agent model and an associated cost model within one acquisition phase. Each year within the phase, the following occur:

- The agent determines its level of effort.
- Based on the level of effort and the probabilities, a value for the performance level is computed.
- The principal's cost incurred is updated with the relevant cost from the year in question.
- Based on the cost incurred, cost growth is measured.

- The estimated time to completion is updated based on the performance for the year.
- The estimated cost for the acquisition phase is updated.
- Cost growth for the acquisition phase is estimated.
- The principal and agent interact, with new probabilities being generated.

At present, we assume that the contract structure and amount are not renegotiated.

Experimental Example

This section describes example simulation results from the cost-plus incentive model described in the Model Description section. The model features a principal and an agent that interact annually over a particular acquisition phase. At each interaction, the probabilities for agent performance change. Cost accrual is tracked, as is time taken to complete the phase by the agent.

Parameters

Tables 1–4 contain parameters used in the simulation example.

Table 1. Probability of Performance

Low Effort			High Effort		
Low	Medium	High	Low	Medium	High
0.6	0.3	0.1	0.1	0.3	0.6

Table 2. Principal's Cost Based on Performance

Low	Median	High
100	200	400

Table 3. Agent's Cost

Low effort	High Effort
50	150

Table 4. Other Parameters

Est. Phase Duration (Yrs.)	Interaction Frequency	Reserve Utility
10	Annually	100

Probabilistic Performance

To model changes in the probabilities (p_i^j) associated with achieving a certain performance level given a level of effort, we use two methods.

- Random assignment. Each p_i^j is assigned a new value from the Uniform (0, 1) distribution, subject to the earlier constraints ($p_0^j > p_1^j > p_2^j$ and $p_i^0 < p_i^1 < p_i^2$).
- Random addition. Each p_i^j is assigned a new value by adding a random amount to the previous value. The new value is $p_i^j(1 + rUnif(-1,1))$, where r = 0.1. This simulates a random walk process. The same constraints are observed, as well as the constraint that $p_i^j > 0 \forall i,j$.

Example Results

Using the random assignment of probabilities, the following results are obtained, as shown in Figure 4. The initial phase duration estimate of ten years was proven to be incorrect, since the phase lasted fifteen years. The estimated cost remained relatively constant, and the final cost ($3,800) was within a 95% confidence interval for the mean of the estimated total costs from each year ($3,727, $3,982).

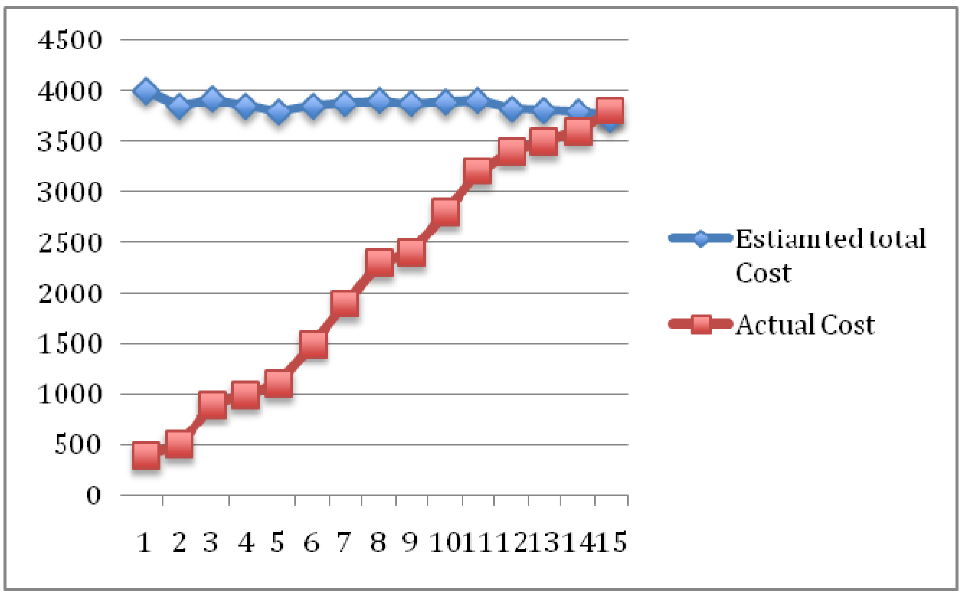


Figure 4. Cost Accrual Using Random Assignment

Under random addition, the following results are obtained, as shown in Figure 5. Similar to the previous example, the initial estimate for phase duration was incorrect, with the actual value being twelve years. The actual cost of $3,600 was likewise within a 95% confidence interval for the mean of the estimated total costs from each year ($3,425, $3,953).

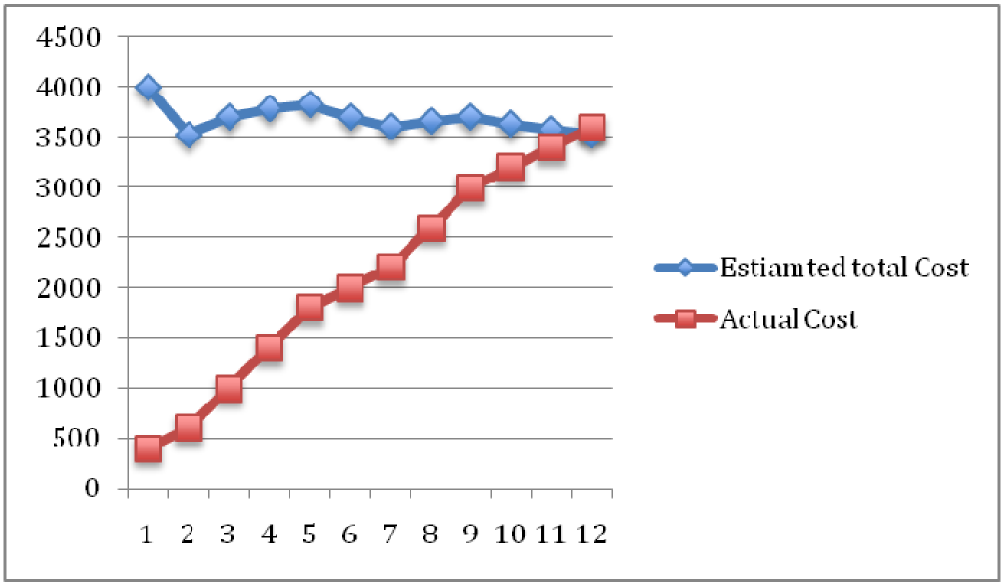


Figure 5. Cost Accrual Using Random Addition

In the second case, there is less variation in the probability values across time as compared to the first case. This is due to the probability update mechanism of the second (random addition), which changes the probabilities within a smaller range than the first. This is due to the relatively small value of *r*. Thus, in the first case, the agent can switch much more readily between low effort and high effort, while in the second case, the switch occurs less often. Thus, we see that this type of variability can drive longer phase durations.

In both examples, there is little to no cost growth. This occurs largely due to three reasons. First, the payment differential between high performance and low performance is relatively large. This motivates the agent to expend high effort. A smaller differential would likely cause increased expenditure of low effort (at relatively higher cost), resulting in cost growth. Second, the example does not use an initial cost estimate derived independently from the estimate used during program performance. Such independent estimates may be artificially low. Finally, technical issues are not modeled that would tend to drive cost growth (e.g., immature technologies, production quality issues). These issues have been demonstrated in previous work (Bodner et al., 2010).

Discussion and Future Research

This paper has presented a model for the acquisition enterprise that addresses its process-oriented aspects, as well as incentives for the actors involved. The incentive model is derived from the principal-agent model used in micro-economics. The acquisition model has been implemented using an organizational simulation framework. Sample results are presented to demonstrate the behavior of a government principal and a prime contractor agent.

Current work addresses the scale-up of the model to more realistic acquisition situations and the integration of more detailed process models (which cover the multi-phase acquisition life cycle and associated technical drivers of cost growth) with the actor models. Of primary interest are programs such as the F-35 Joint Strike Fighter. In this program, cost growth has been an issue, due to technical process issues and due to incentives. In addition, the F-35 employs a systems integrator paradigm of acquisition in which the prime contractor integrates complex subsystems designed and produced by a network of other contractors. This paradigm is relatively new, since it was preceded for many years by the manufacturer paradigm, in which most design and production were performed by the prime contractor, with relatively simple subsystems contracted out according to the prime's specifications. It is increasingly being used in acquisition of complex systems by the DoD and the industry (e.g., Boeing Dreamliner). The systems integrator paradigm implies the need for extensive research in incentives and contract structures. Due to the complexity of supply networks, simulation will be a valuable tool in this type of research.

References

Birkler, J., Bower, A. G., Drezner, J. A., Lee, G. T., Lorell, M. A., & Smith, G. K. (2003). *Competition and innovation in the U.S. fixed-wing military aircraft industry*. Santa Monica, CA: RAND.

Birkler, J., Graser, J. C., Arena, M. V., Cook, C. R., Lee, G. T., Lorell, M. A., Smith, G. K., Timson, F., Younossi, O., & Grossman, J. (2001). *Assessing competitive strategies for the Joint Strike Fighter*. Santa Monica, CA: RAND.

Bodner, D. A. (2009). A first-generation reference model for organizations to support organizational simulation (Unpublished technical report). Tennenbaum Institute, Georgia Institute of Technology, Atlanta, GA.

Bodner, D. A., Mutnury, B., Cases, M., & Rouse, W. B. (2009). Modeling design services for improving service delivery effectiveness. In *Proceedings of DesignCon 2009*. Santa Clara, CA.

Bodner, D. A., Rahman, F., & Rouse, W. B. (2010). Addressing cost increases in evolutionary acquisition. In *Proceedings of the Seventh Annual Acquisition Research Symposium* (Vol. I, pp. 329–345). Monterey, CA: Naval Postgraduate School.

Bodner, D. A., & Rouse, W. B., (2007). Understanding R&D value creation with organizational simulation. *Systems Engineering*, *10*(1), 64–82.

Candreva, P. (2009). Examining the institutional factors affecting cost growth in defense acquisition: Additional insights may yield more effective policy interventions. In *Proceedings of the Sixth Annual Acquisition Research Symposium* (Vol. II, pp. 258–259). Monterey, CA: Naval Postgraduate School.

GAO. (2005). *DOD has paid billions in award and incentive fees regardless of acquisition outcomes* (Report GAO-06-66). Washington, DC: Author.

GAO. (2009a). *Assessments of selected weapon programs* (Report GAO-09-326SP). Washington, DC: Government Accountability Office.

GAO. (2009b). *Joint Strike Fighter: Strong risk management essential as program enters most challenging phase* (Report GAO-09-711T). Washington, DC: Author.

GAO. (2011). *Assessments of selected weapon programs* (Report GAO-11-233SP). Washington, DC: Author.

Gilbreth, A. S., & Hubbard, S. (2008). How to make incentive and award fees work. *Defense Acquisition Review Journal*, *15*(2), 132–149.

Hildebrandt, G. G. (2009). Effect of information and decision-making on DoD performance incentives and award fees. In *Proceedings of the Sixth Annual Acquisition Research Symposium* (Vol. II, pp. 10–21). Monterey, CA: Naval Postgraduate School.

Hillebrand, E., & Stender, J. (1994). *Many-agent simulation and artificial life*. Amsterdam: IOS Press.

Kapstein, E. B. (2004). Capturing Fortress Europe: International collaboration and the Joint Strike Fighter. *Survival*, *46*(3), 137–160.

Kratz, L. A., & Buckingham, B. A. (2009). Achieving performance-based lifecycle management. In *Proceedings of the Sixth Annual Acquisition Research Symposium* (Vol. I, pp. 147–161). Monterey, CA: Naval Postgraduate School.

Kreps, D. (1990). *A course in microeconomic theory*. Princeton, NJ: Princeton University Press.

Law, A. M., & Kelton, D. W. (2000). *Simulation modeling and analysis* (3rd ed.). New York, NY: McGraw-Hill.

National Commission on Fiscal Responsibility and Reform (NCFRR). (2010). $200 billion in illustrative savings. Washington, DC: Author.

Pennock, M. J., & Rouse, W. B. (2008). The costs and risks of maturing technologies, traditional vs. evolutionary approaches. In *Proceedings of the Fifth Annual Acquisition Research Symposium* (pp. 106–126). Monterey, CA: Naval Postgraduate School.

Reifer, D. J., & Boehm, B. W. (2006). Providing incentives for spiral developments: An award fee plan. *Defense Acquisition Review Journal*, *13*(2), 62–79.

Rouse, W. B., & Bodner, D. A. (2009). Organizational simulation. In A. P. Sage and W. B. Rouse (Eds.), *The handbook of systems engineering and management* (2nd ed., pp. 763–792). New York, NY: John Wiley & Sons.

Rouse, W. B., & Boff, K. R. (Eds.). (2005). *Organizational simulation: From modeling & simulation to games & entertainment*. New York, NY: Wiley.

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Boston, MA: McGraw-Hill.

Tremaine, R. L. (2008). Incentive contracts: The attributes that matter most in driving favorable outcomes. *Defense Acquisition Review Journal*, *15*(3), 217–237.

Acknowledgments

This material is based upon work supported by the Naval Postgraduate School under Award No. N00244-09-1-0015. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Naval Postgraduate School.

Georgia Tech Tennenbaum Institute

Knowledge and Skills for Enterprise Transformation.

The Effect of Processes and Incentives on Acquisition Cost Growth

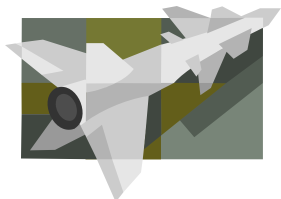
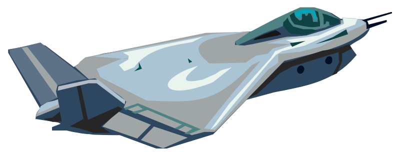
Doug Bodner, I-Hsiang Lee and Bill Rouse

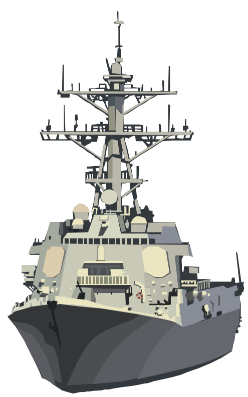
Agenda

Georgia Tech Tennenbaum Institute

- Motivation
- Cost growth
- Model
- Simulation implementation
- Simulation results
- Current work

Motivation

- Cost growth evident in weapons programs
  - $296 billion in 2008 portfolio
  - $135 billion since 2008
  - $70 billion unexplained by quantity changes
- Pressure to rein in costs due to fiscal and political environment
- Decision-making regarding processes and incentives

Process Drivers

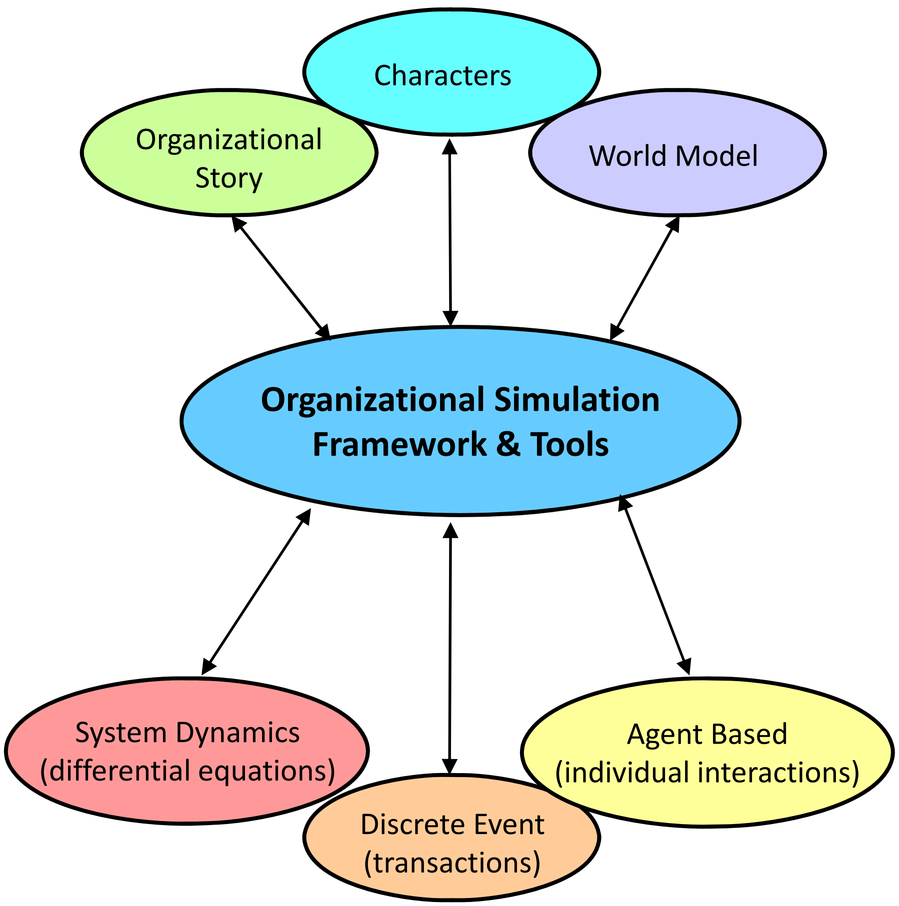
- Evolutionar¸ ac ˛uisition
  - Each development cycle occurs at lower cost
  - Increased number of development cycles contributes to potentially higher cost
- Phase concurrency
  - Concurrency might be used to regain schedule (e.g., between development and production)
  - Concurrency introduces risk of rework and wasted production
- n rt int¸
  - Technology immaturity poses cost growth risk
  - Requirements volatility poses cost growth risk

Incentive Drivers

Georgia Tech Tennenbaum Institute

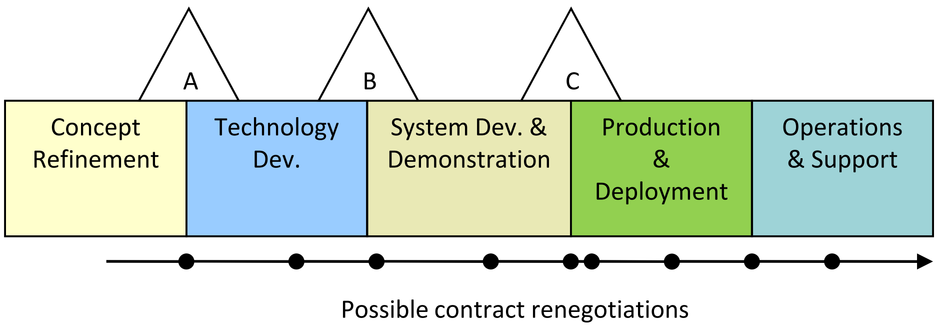
- Cost-plus contracts
  - Cost growth tends to be enabled
- Competition vs. non-competition
  - Competition should incentivize cost performance
  - Low bids are potentially incentivized by competition
- Incentives
  - Evidence shows award/incentive fees ineffective
  - Recommendations for using fees include
    - Set base fee and tie overall fee to outcomes, not time
    - Using rollovers judiciously

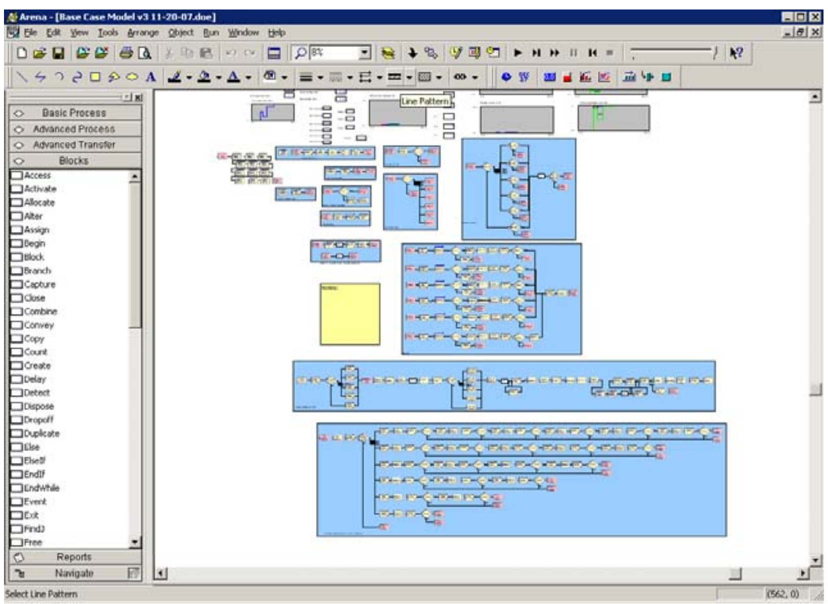
Organizational Simulation



- Simulation methodology focused on the organizational experience
  - People
  - Social behavior
  - Rules and processes
  - Artifacts
  - Architecture
- Tools for designing, testing, prototyping and experimenting with organizational systems
- AnyLogic implementation with Java class library for organizational modeling

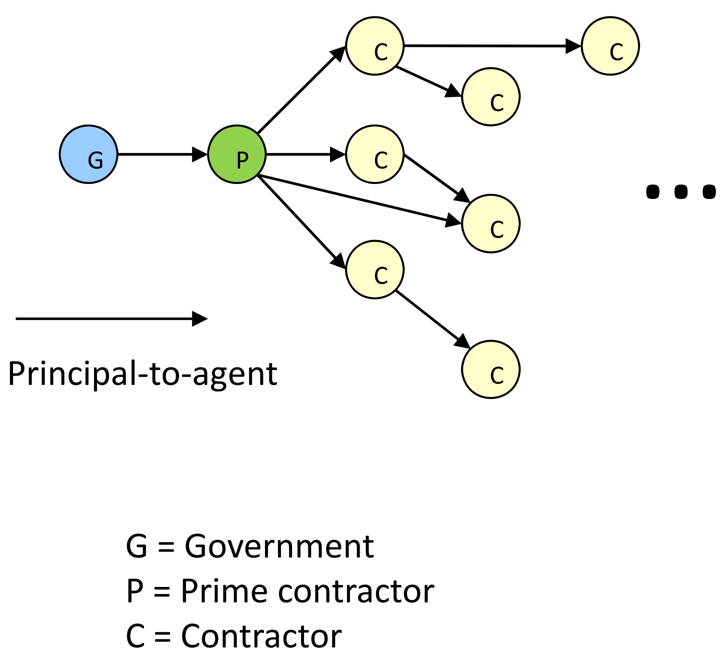
Process Model





- Acquisition phases
- Decision points
- Cost accruals
- Progress
  - Technology maturation
  - Design
  - Development
- Concurrency and uncertainty
- Contract renegotiations

Actor Model



- Principal-agent model
  - Government as principal
  - Contractor as agent
- Are the interests of the agent aligned with those of the principal?
  - Contract structure
- Eventually extended to multi-tier principal-agent network
  - Complex
  - Non-transparent

Incentive Model

- Agent has a utility $U(w, a)$ from working for the principal
  - w = payment
  - a = effort
  - Reserve utility in case of no contract
- Payment each period
  - x_0^2 for low performance
  - x_1^2 for medium performance
  - x_2^2 for high performance
- Performance based on effort, incorporating uncertainty
  - $P(a_i) = P_j$ with probability p_j^i
  - Probabilities scaled so that lower efforts have higher probabilities of low performance and vice-versa

Optimization

- Principal's perspective
- Minimize expected payout
- Subject to
  - Agent's expected utility ≥ reservation utility
  - Agent's expected utility for high effort ≥ expected utility for low effort

Cost-Plus

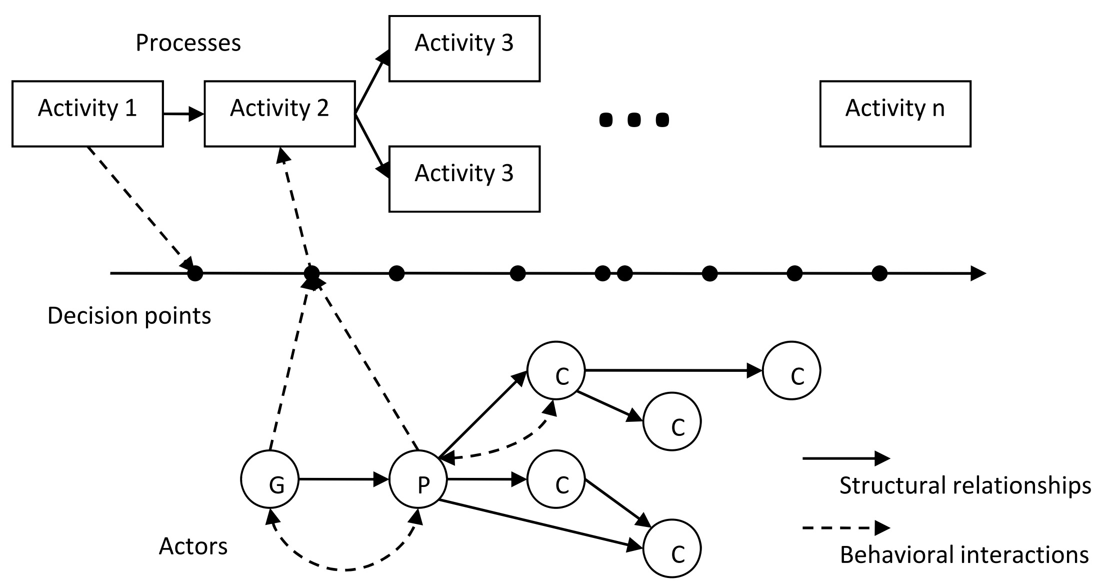
- Let T be total time for an acquisition phase, and let there be an estimate of time remaining at time t
- Agent's progress each period goes toward completion time, and estimate of time remaining is updated
- Principal pays x_i^2 per period depending on performance level
- An initial cost estimate is provided, and is updated with actual cost incurred plus an estimate for the remaining phase duration
- Cost growth and incremental cost growth can be measured by the difference of the actual and the estimate at time t

Fixed Price

- Assume Cobb-Douglas production function with increasing returns to scale
- Production efficiency is a function of effort, incorporating uncertainty
  - $\alpha(a_i) = \alpha_j$ with probability p_j^i
- Agent selects level of effort to maximize expected gain
  - Price per unit multiplied by number of units less expected cost to agent based on production function
- Discussion
  - Production efficiency of concern primarily to agent
  - Principal concerned with schedule
  - Discounted cash flows and penalties

Simulation Implementation

- Agent determines effort
- Performance level computed
- Cost incurred updated
- Estimated time to completion updated
- Estimated cost updated
- Cost growth estimated
- New probabilities generated



Probabilities

- Probabilities change at each period
- Random assignment
  - Each probability is assigned a new value from the Uniform (0, 1) distribution, subject to the earlier constraints
- Random addition
  - Each probability is assigned a new value by adding a random amount to the previous value
  - The new value is the probability multiplied by (1+*r*Unif(-1,1)), where *r* = 0.1
  - This simulates a random walk process
  - The same constraints are observed, as well as the constraint that probabilities are non-negative

Experimental Example

Probability of performance

Low Effort			High Effort		
Low	Medium	High	Low	Medium	High
0.6	0.3	0.1	0.1	0.3	0.6

Principal's cost based on performance

Low	Median	High
100	200	400

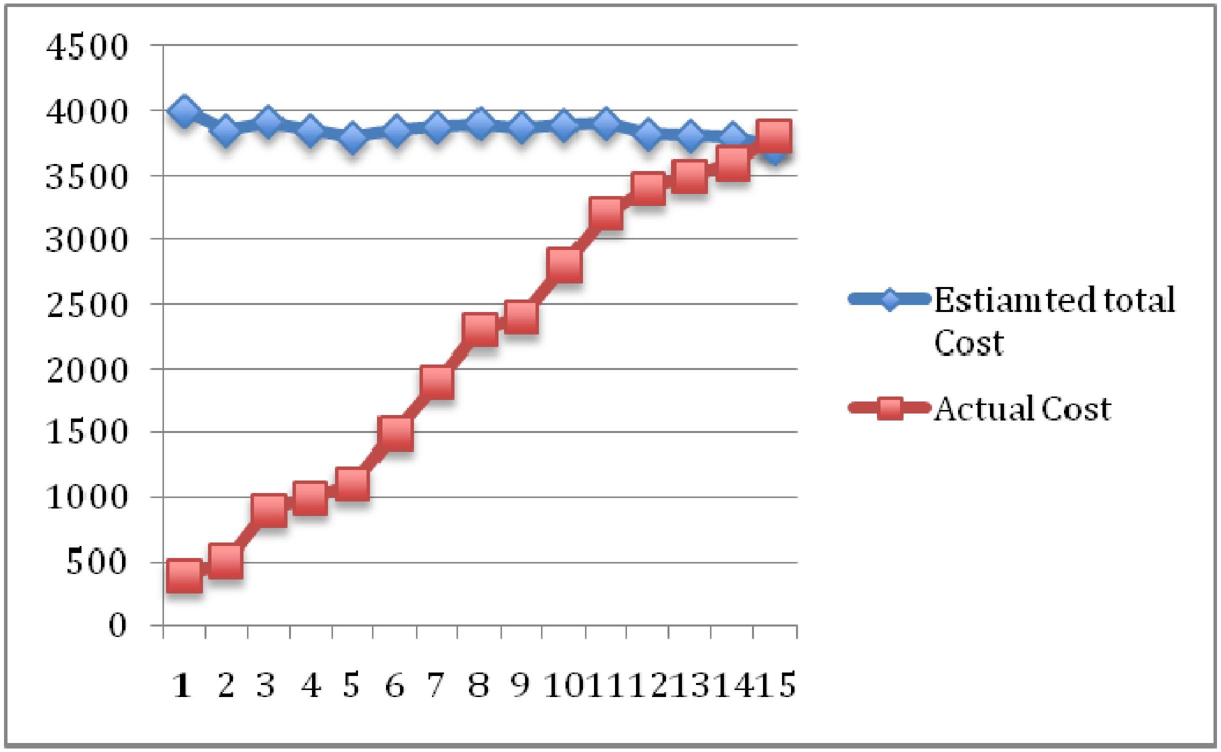
Agent's cost

Low effort	High Effort
50	150

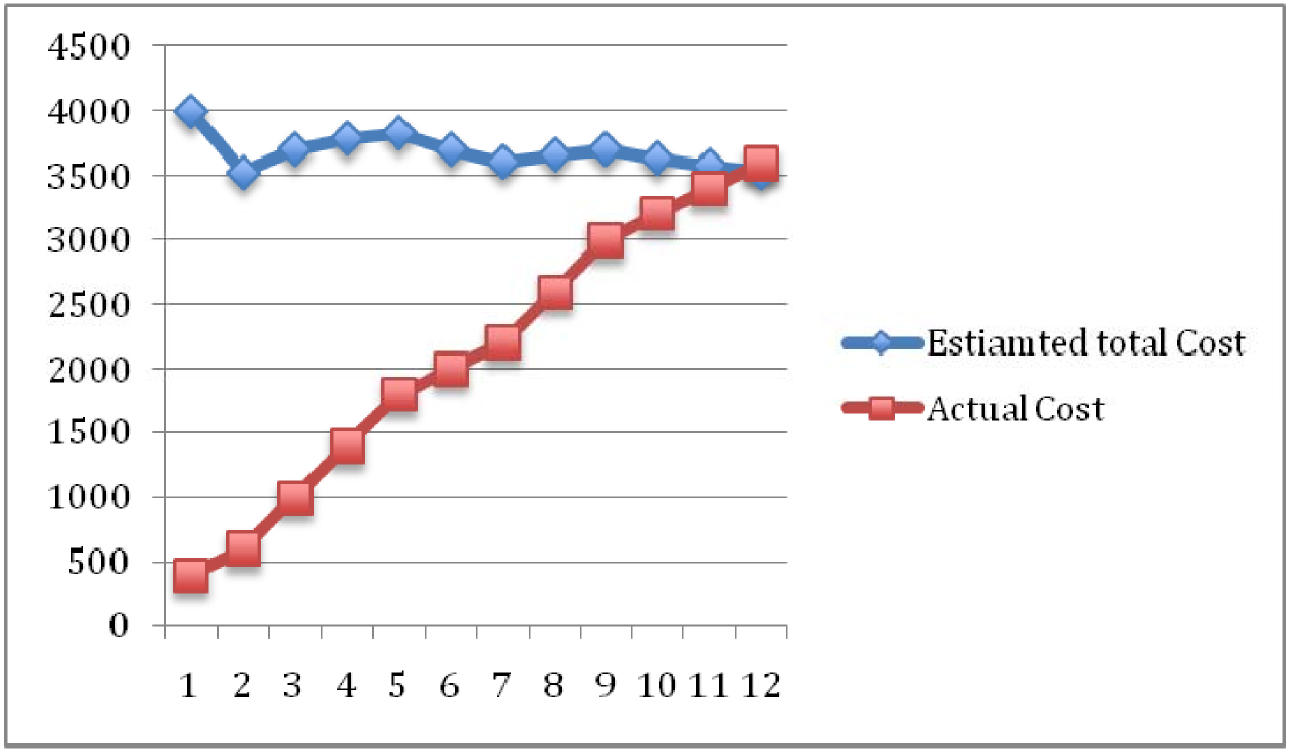
Other parameters

Est. Phase Duration (Yrs.)	Interaction Frequency	Reserve Utility
10	Annually	100

Random Assignment



Random Addition



Equal Probabilities

	Random Assignment		Random Addition	
	Original	Equal Prob	Original	Equal Prob
Mean	177.3	185.3	169.5	175.9
Std. Dev.	61.2	60.7	76.0	47.2

- Random addition has a lower variance than random assi¸nment due to the ¸enerall¸ smaller chan¸es in probabilities between periods
- This difference is smaller under the equal initial probabilities since there is less switching between effort levels

Discussion

- Combined process and incentive modeling
- Micro-economic and technical behavior models
- Contract structure
- Simulation needed due to complexity

Current Research

Georgia Tech Tennenbaum Institute

- Scale up work with F-35 data and multi-tier , rinci, al-agent network
- Enhance fixed cost model
- Experimentation with incentive structures, transfer points and process concurrency

Acknowledgments

Georgia Tech | Tennenbaum Institute

- This material is based upon work supported by the Naval Postgraduate School under Award No. N00244-09-1-0015.
- Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Naval Postgraduate School.

Questions

?

?

?

?

?

?

?

?